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(54) Title: A MICRO RELAY

(57) **Abstract:** This invention relates to the area of microelectromechanical systems and micro relays and micro switches. The relays disclosed allow high currents, inductive loads, and high frequencies to be controlled using a relay that increases its resistance during opening and decreases its resistance during closing.

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A MICRO RELAY

Field of the Invention

This invention relates to the area of microelectromechanical systems and micro relays and micro switches. The invention is particularly concerned with mechanical relays and switches that can reliably control higher currents, inductive loads, and high frequencies.

Background of the Invention

Many problems can occur when miniaturizing, or micro sizing, relays. These problems can make micro relays unreliable. One problem with micro relays is that they tend to rapidly wear out. As the size of a relay is scaled down, the amount of material contained in the relay's electrical contacts decreases rapidly. For an example, if the size of a relay is scaled down by a factor of a thousand, the amount of material in an electrical contact decreases by a factor of one billion, the surface area of the contact decreases by a factor of one million, and the distance the switch moves to closure decreases by a factor of a thousand. On conventionally sized, or macro sized, relays the contacts can wear due to friction with other components and because of arcing and the formation of insulating oxides on contact surfaces that can be removed by a slight abrading action. While a macro relay has sufficient material for the removal and corruption of contact material, the small amount of material in a micro relay contact can be quickly destroyed.

In addition, the small size of the micro relays makes the relays more susceptible to dust and dirt. In a micro relay, small amounts of dust can cover the

contact. Conventionally sized relays would still have sufficient contact area around a small dust particle to make a suitable contact.

Another problem is that micro relays are more prone to arcing and burning than conventional size relays. Micro relays have smaller gaps between the contact points. Arcing is more prone to occur across these smaller gaps than to occur across the larger gaps in a conventional sized relay. The arcing of micro relays in addition to causing damage to the relay can also generate RF noise and signals, which can interfere with other electronic components.

Micro relays can only carry a limited amount of electricity because of their small size. Unfortunately, if several relays are put in parallel to increase the total current carrying capability of the several relays, the relays tend to burn out, first one then another. Specifically, the relays open at slightly different times, and the last one to open carries the full current of the several relays. This high current increases the likelihood that the contacts will burn, melt, or arc the contact. The likelihood that the contacts will be damaged or destroyed by high current is especially probable if the several switches are trying to switch an inductive or radio frequency, RF, load. An inductive load, for example, tries to maintain the current flow as the switch opens, and can generate high voltages to sustain the current flow. (This is how the high voltage for the spark plugs in a car is generated.) RF sources are also known for their ability to arc across small gaps such as the opening contacts micro relays.

Figure 1 and figure 2 show a conventional micro switch. In figure 1 the micro switch sits upon a substrate, with inputs A and B on either side of the substrate. In the center is a bar that shorts between the inputs to close the switch.

Figure 2 shows the switch in its open position, where the bar has moved away from the input connector A. There is now an air gap separating inputs A and B. In the

process of opening between figure 1 and figure 2, there is an abrupt breaking of the contact when the connecting member separates from the input connector A.

Summary of the Invention

In order to control the flow of high currents, inductive loads, and high frequencies, this invention provides using relays that increase their resistance during opening and decrease their resistance during closing.

In one embodiment, the invention provides a relay comprising a substrate, a variable resistance contact attached to the substrate, and a connecting member. The resistance of the variable resistance contact varies along its length. The connecting member is configured to contact the variable resistance contact at positions of increasing resistance during opening and decreasing resistance during closing of the relay.

Preferably, the relay is less than 2 millimeter in length. Preferably, the variable resistance contact is a serpentine conductor. Preferably, the connecting member is flexible. Preferably, the flexible member is curved away from the substrate when the relay is open. Preferably, the connecting member is configured to respond to an electrostatic force. Preferably, the electrostatic force is produced by inter-digitated electrodes attached to at least one surface of the substrate or connecting member. The connecting member can also preferably be configured to respond to a magnetic force, a piezoelectric force, a thermally generated force, a force produced by bimorph, or a force produced by a boiling bubble.

Preferably, the relay has a second contact with a non-conducting layer existing between the variable resistance contact and the second contact when the relay is open. Preferably, the non-conducting layer is a sacrificial layer.

Preferably, the relay is fabricated using a layer of silicon dioxide between the contact points that is later dissolved in a solution containing hydrofluoric acid. Preferably, the variable resistance contact is a conductor made of gold, platinum, chrome, titanium, or mercury. Preferably, the substrate comprises a silicon surface or a glass surface.

Preferably, a plurality of relays are placed in parallel and series to produce an array. Preferably, resistors are placed between the relays of the array so that the resistance of the array can be controlled by opening and closing relays in the array.

In another embodiment, the invention provides a method of preventing arcing between a contact and a connecting member in a relay. The method comprises providing a relay comprising at least one variable resistance contact and at least one connecting member. The resistance of the variable resistance contact varies along its length. The variable resistance contact is contacted at positions of increasing resistance during opening of the relay and contacted at positions of decreasing resistance during closing.

In another embodiment, the invention provides a dynamic antenna comprising a plurality of antenna elements. Relays interconnect the antenna elements. The relays comprise a substrate, a variable resistance contact attached to the substrate, and a connecting member configured to make electrical contact at several positions along the variable resistance contact. The resistance of the variable resistance contact varies along its length.

Preferably, the configuration of the dynamic antenna can be changed by connecting together antenna elements by closing individual relays. Preferably, the impedance of the antenna is changed when the configuration of the antenna is

changed. Preferably, the antenna elements and the relays are fabricated on the same substrate. Preferably, antenna elements comprise a conducting metal.

Preferably, the relays in the dynamic antenna further comprise three electrodes beneath the connecting member. Preferably, the three electrodes are connected to three different control lines. Preferably, the three control lines are used to control the opening and closing of the multiple relays of the dynamic antenna in a multiplexed manner.

In another embodiment, the invention provides a method of making a dynamic antenna. The method comprises providing a plurality of antenna elements on a substrate, and connecting each antenna element to each adjacent element using a relay. The relays in the dynamic antenna comprise a substrate, a variable resistance contact attached to the substrate, and a connecting member configured to make electrical contact at several positions along the variable resistance contact. The resistance of the variable resistance contact varies along its length.

In yet another embodiment, the invention provides a relay array comprising a plurality of relays. The relays of the relay array comprise a substrate, a variable resistance contact attached to the substrate, a connecting member configured to make electrical contact at several positions along the variable resistance contact, and three electrodes placed beneath the connecting member. The resistance of the variable resistance contact varies along its length. The connecting member makes electrical contact to the variable resistance contact at positions of increasing resistance during opening and decreasing resistance during closing. The three electrodes are connected to three different control lines.

Preferably, the relay array is closed by activating all three electrodes beneath the relay's connecting member. Preferably, a closed relay in the relay array can be

maintained in the closed position by a single active electrode. Preferably, the three different control lines are connected to a plurality of relay electrodes in the array. Preferably, the three control lines are used to control the opening and closing of multiple relays of the relay array in a multiplexed manner.

Brief Description of the Drawings

Figure 1 is a perspective view of a prior art relay;

Figure 2 is a front view of the prior art relay of figure 1;

Figure 3 is top view of a set inter-digitated electrodes;

Figure 4 is a perspective view of one embodiment of a relay;

Figure 5 is a front view of the relay of claim 4;

Figure 6 is a perspective view of the relay of claim 4 with the connecting member removed;

Figure 7 is a top view of a dynamic antenna;

Figure 8 is a top view of one embodiment of a programmed dynamic antenna;

Figure 9 is a top view of a second embodiment of a programmed dynamic antenna;

Figure 10 is a top view of a third embodiment of a programmed dynamic antenna;

Figure 11 is a top view of a fourth embodiment of a programmed dynamic antenna;

Figure 12 is a top view of a fifth embodiment of a programmed dynamic antenna;

Figure 13 is a top view of a sixth embodiment of a programmed dynamic antenna;

Figure 14 is a front view of a relay for a dynamic antenna;

Figure 15 is close up view of antels and relays of a dynamic antenna.

Detailed Description of the Invention

This invention relates to both relays that have an actuator to close the electrical contact, and switches that are closed by external influences such as a manually operated lever. Both the relays and switches will be hereafter referred to as relays.

The present invention is a relay in which the resistance of the relay increases gradually during opening, and decreases gradually during closing, rather than the abrupt opening and closing of the contacts in a conventional relay. This gradual increase can help absorb and dissipate the energy in the circuit, including the energy associated with inductive and RF loads, greatly reducing damage to the relay.

A circuit carrying an inductive load can illustrate the benefits of the present invention. When a conventional switch opens, the resistance increases dramatically, typically from less than an ohm to over several million ohms. The inductive load will generate a voltage spike as it attempts to keep the current flowing. This voltage spike is what arcs across a conventional switch, causing the relay contacts to burn and oxidize and pit. In the present invention, when the switch starts to open, the resistance increases gradually, and the inductive load dissipates across the increasing resistance. By the time the relay finally opens, the resistance across the relay is quite large, and the current still flowing is quite small.

The same phenomenon happens with a RF load across the switch. As the switch opens, the resistance (and in this case also the inductance) increases, causing the current flow through the switch to decrease until the switch can open safely with out arcing when it finally does open completely.

The gradual opening of the relay also greatly improves the performance of relays operating in parallel. The gradual opening allows for a more even distribution

of current across several opening relays when operated in parallel. The micro relays of the present invention open over a longer period of time than a typical relay and resistively dissipate energy as they open. So even though relays operated in parallel may begin opening at slightly different times, other parallel relays can begin opening before the first relay is completely open. This allows the voltage to be dissipated across all of the relays that are concurrently, gradually, opening. Although slower than typical relays, the gradual opening is still rapid compared to many phenomena and the dissipation of electricity across the relay is rapid compared to the rate of opening the mechanical relay. The actual rate of opening of the relay will depend on many things including the scale of the micro relay and the force used to open the relay.

A relay embodying the present invention can be of any scale, including full scale, although it has been found that the benefits of the present invention are particularly useful in small relays. The term micro relay herein refers to relays smaller than 2 millimeters in length. Preferably the length of the micro relay is less than 2 millimeters, more preferably less than 1 millimeter, and even more preferably less than 100 microns.

One embodiment of the present invention is a relay that has two contacts. The two contacts have a non-conducting gap between them. A conducting connecting member spans the gap between the two contacts. The connecting member can be permanently connected to one of the two contacts. When the connecting member is in the closed position, the connecting member can make detachable contact with the other contact allowing current to flow from one contact to the other. When the connecting member is in the open position, the connecting member is detached from one of the contacts.

In the present invention, the contact that the connecting member makes detachable contact with has varying resistance. As the contact closes, the connecting member is designed to touch the varying resistance contact at a point of high resistance and slowly contact the varying resistance contact at points of lower and lower resistance. In this manner the current in the relay is slowly increased as the relay closes. When the relay opens, the process is reversed. The connecting member slowly detaches itself from the varying resistance contact. Detachment is made first at points of lowest resistance and then at points of higher and higher resistance. In this manner the current is slowly cut-off from the circuit as the circuit opens.

The varying resistance contact can be made in any manner that allows the contact to have varying resistance at different points on the contact. A preferable varying resistance contact is a serpentine contact made of a conducting material. A serpentine contact is a contact that zig-zags back and forth perpendicular to the direction that the connecting member closes. The serpentine contact becomes finer in the direction of its end point. Both the length of the contact and the fact that the contact becomes finer in the direction of its end point gives the contact varying resistance along its length. The zig-zag configuration of the contact allows the contact to make greater contact with the connecting member at points along the contact. Another preferable method of increasing the resistance of the contact along its length is to use less conductive materials along the length of the contact.

The variable resistance contact, and specifically the serpentine contact, in addition to dissipating current during relay opening and closing also provides an extended contact region with several contact points. The extended contact region allows for some of the contact points of the relay to be damaged by slight arcing while still allowing the relay to operate. This is because this damage will most likely be at

the end of the relay where little current flows through the relay. In addition, if one of the contact points on the variable resistance contact is damaged, the relay can have other contact points that still operate allowing the switch to still carry a current. The extended contact and multiple contact points also make the relay less susceptible to wear and dirt. Some of the contact points can wear out or become covered by dirt while other contact points are still operable.

The metalization of the contacts is important. Preferred materials are hard enough to withstand repeated closures, have high conductivity, can deform slightly to make a larger area contact, and do not oxidize readily. Gold, platinum, chrome, titanium, and a host of other materials can be used as the contact material.. Often, using two different materials on the two contacting surfaces improves the lifetime of the contacts. Where it is allowed environmentally, mercury also makes an excellent contact with a long lifetime.

The contacts are preferably mounted on a non conducting substrate. Preferable substrates include silicon dioxide, and glass substrates. The contacts should be mounted sufficiently far apart to prevent arcing when the relay is open. In a preferred embodiment the non conducting part of the substrate is a sacrificial layer. Such a layer could be made of silicon dioxide, which could later be dissolved using hydrofluoric acid to produce other components of a circuit.

Preferably the connecting member is a curved membrane that progressively touches the varying resistance contact as it closes. Preferably the connecting member is curved away from the varying resistance contact. When the relay is closed, the connecting member is made to bend towards the varying resistance contact progressively touching the contact at lower and lower resistive points until the relay is completely closed. If a serpentine contact is used, this action allows the high

resistance contacts on the serpentine conductor to be made first, and as the bar progressively closes to the surface, lower and lower resistance contacts are made until the bar finally shorts between the two contacts making a low resistance path.

Another preferable arrangement is a straight connecting member and a curved substrate. In this arrangement, the connecting member is made to curve around the substrate to contact the varying resistance contact at different points. Yet another preferred arrangement is a relatively flat connecting member and a flat substrate. The connecting member could then be made to touch the varying resistance contact by flexing the connecting member, the substrate, or both. Another preferred arrangement is to have the contact surfaces on the varying resistance contact mounted on springs of appropriate length to enable the correct sequence of increased resistance during contact closure.

Part or all of the connecting member can be conducting. In a preferred embodiment, a conducting metal is deposited upon a flexible substrate. The flexible substrate allows the connecting member to flex during relay opening and closing.

A flexible connecting member can be manufactured by a number of effective techniques. A preferred connecting member, for micro relay designs, can be manufactured using electronic silicon fabrication techniques. The connecting member can be manufactured using a thin silicon layer as a substrate. Such a layer can be comprised of, for example, poly silicon or silicon nitride, deposited using electronic silicon fabrication techniques.

The connecting member can be formed from the relay's substrate by removing a layer of material from beneath the portion of the substrate that will become the connecting member. By removing a layer of substrate material a flap can be formed on the substrate. Material beneath the connecting member can be removed using

silicon surface micro machining technology such as dissolving silicon dioxide in a hydrogen fluoride solution. Curving the flap to form the connecting member can be accomplished by depositing a metal, such as aluminum, on the top surface of the connecting member. Deposited aluminum is usually under tension and will cause the connecting member to curve as desired. Metal or a conductive layer may be deposited on both sides of the connecting member to improve conduction across the connecting member and reduce the closed resistance of the relay. One or more of these conducting layers may also improve the contact closure of the relay.

The operating parameters for a relay according to the present invention can varying according to the scale of the relay, the materials used in the relay, and the specific relay design used. For example, the connecting member may be 40 microns long, 10 microns wide, and 1 micron thick. Typical parameters for a switch of this general description are: open capacitance about 0.1 femto farad, closed resistance about 1 ohm, switch time about 100 micro seconds, current about 100 milliamperes, and breakdown voltage about 500 volts. These parameters can be varied over a wide range of specifications depending upon the particular design of the micro relay.

The relay can be actuated using many different physical principals. In a preferred embodiment, the substrate and connecting member each contain conducting plates. When a voltage is placed between these plates, an electrostatic force causes the connecting member to be attracted towards the substrate and the varying resistance contact attached to the substrate. A curved shaped connecting member requires less voltage to operate than a connecting member and substrate that are configured as two parallel plates separated by some distance. This lowering of the operating voltage is described in the paper "Microactuators for Aligning Optical Fibers" by R. Jebens, W. Trimmer, and J. Walker, published in "Sensors & Actuators," 1989, pp. 65 to 73, and

reprinted in the book "Micromechanics and MEMS, Classic and Seminal Papers to 1990," Edited by William Trimmer, page 237.

If electrodes on the connecting member and the substrate are used to actuate the micro relay, the electrodes on the substrate can be placed along side the varying resistance conductor in such a way that the connecting member overlaps the substrate electrodes. Alternatively, the electrode on the substrate can be placed below the varying resistance conductor, and preferably insulated from the conductor by an insulating layer.

The electrodes on the substrate or on the connecting member can be inter-digitated fingers of conducting electrodes, as shown in figure 3. When voltage is applied between input 304 and input 306, an electric field is set up between the inter-digitated fingers of conductor 300 and conductor 302. Either an alternating, a.c., or a steady state, or d.c., voltage can be applied between input 304 and input 306 on the inter-digitated conductors 300 and 302 to generate electric fields between the interdigitated fingers. The inter-digitated conductors 300 and 302 can be on one surface, and a conductor on the other surface. Alternatively the inter-digitated conducting electrodes 300 and 302 could be on both surfaces. Either arrangement can be used to cause an attractive electrostatic force between the substrate and the connecting member. The inter-digitated conducting electrodes 300 and 302 as shown in figure 6 are less susceptible to many phenomena that reduce the electrostatic force generated, for example trapped surface charges and depleted regions. A slightly conducting insulator can be used to cover the inter-digitated electrodes or between the substrate and the connecting member to reduce problems with surface charge.

Electrodes can be placed on the substrate and connecting member in a number of other ways, for example multiple layers of electrodes or regions of trapped charge could be used in some designs to facilitate the electrostatic force.

In another preferred embodiment, the relay is actuated using a thermal bimorph. A bimorph is formed by bonding together two materials of differing thermal expansion, as the temperature changes the bimorph will bend. The connecting member can be fabricated from two or more such materials possessing different thermal expansion properties to provide the appropriate bending. To actuate this actuator, a resistive heater can be placed on the bimorph.

In yet another preferred embodiment the relay is actuated magnetically. Electromagnetic coils or a permanent magnet can be placed on the connecting member. The connecting member can then be moved by changing the magnetic field around the connecting member. In another embodiment, a solenoid external to the connecting member is used to controllably attract the connecting member towards the varying resistance contact.

In another preferred embodiment the relay is actuated piezoelectrically. A piezoelectric material produces a mechanical force when a voltage is applied. For example, a connecting member can be formed from one or more piezoelectric materials forming a piezoelectric bimorph. A voltage can then be applied to the connecting member to make the piezoelectric bimorph bend in a suitable manner. Instead of a piezoelectric bimorph a single or stack of piezoelectric material can also be used to actuate the micro relay. A promising piezoelectric material is called sol-gel, and can be spun on a silicon wafer and integrated with other electronic silicon fabrication technology process steps.

Many other methods can be used to actuate the relay. Other actuating methods include the use of fluidics and pressure related forces, manual activation (i.e. a person touching a surface), accelerations, surface tension, and many other actuation methods know in the art.

The extended opening time of the relay also allows many relays to be operated in parallel without excessive relay burnout. In a set of conventional relays operated in parallel, the last relay to open takes the full inductive load or sees the full RF field. In time, this relay will burn out, leaving one fewer relays. Now the next slowest relay burns out, and this continues until all the relays have failed, or the remaining relays can no longer sustain the current through the switch. In the present invention, all of the relays can open simultaneously over an extended period. Each relay handles part of the inductive or RF load, and dissipates the energy associated with that load as the resistance of the relay increases. By the time the parallel relays start to completely open, the current has been dramatically reduced by the present high resistance of the relays, and there is little current or energy left.

The relays of the present invention can also be operated in an array, say of 10 rows and 10 columns. Operating relays in an array increases both the current carrying capability of the relay array and also the reliability. If one relay fails in the open position, the relays in parallel with this relay are sufficient to carry the load. If one relay fails in the closed position, the relays in series with this shorted relay are still open, and block the flow of current. The larger the array, the more relays that can fail and still have the array of relays function properly. This array of relays is difficult to implement with conventional relays because, as described above, the last opening relay tends to burn, setting of a chain reaction of relay failure. Also, using an array of 10 by 10 relays would be expensive using conventional macro switches because of the

need to purchase 100 relays. However using microfabrication techniques, a large number of micro relays can be fabricated simultaneously, for often not much more expense than one macro relay.

Another advantage of the present invention is a large array of relays can be multiplexed. For example, an array of 100 relays which is organized as a square array of ten rows and ten columns, can be controlled with ten row control lines and ten column control lines and 10 latching lines for a total of 30 signal lines. If these relays were not multiplexed at least 100 control lines would be needed. This multiplexing reduces the complexity, the number of interconnects, and the amount of electronics to control these relays. As the number of relays increases, this multiplexing becomes even more advantageous. In one application, each micro relay is in series with a particular resistor. By opening and closing the appropriate relays, the total resistance of the relay array can be conveniently controlled. This might be especially useful in applications such as feed back circuits in operational amplifiers.

Combinations of micro relays can also be used to form an "intelligent antenna." An array of micro relays can be used to dynamically reconfigure an antenna. The use of these micro relays opens a whole new world of antenna design. An antenna produced using the relays as previously described are more durable since these relays can handle high loads, and particularly RF loads, with minimal burning and arcing.

A preferred antenna is one that can dynamically change its size and shape as the electronics changes frequency. The antenna can change their impedance to correct for mismatches in the electronics. To focus the antenna in a different direction, the antenna simply changes shape. Such an antenna can be an array of antenna elements made out of a conducting material. The antenna elements are interconnected using

micro relays. The size and shape of the antenna can then be changed as needed by connecting the desired set of antenna elements by opening and closing the appropriate relays.

A dynamic antenna using micro relays could be as small as 4 inches in diameter, a millimeter thick and contain 100,000 antenna elements. Alternatively the dynamic antenna might be a surface several meters across tiled with smaller intelligent antenna segments.

Figures 4, 5, and 6 show one embodiment the present invention. In figure 4, a relay 400 comprises a first contact 402, a second contact 404, a connecting member 406, and a substrate 408. The first contact 402 is a serpentine conductor that zig-zags back in forth perpendicular to the connecting member 406. The connecting member 406 is permanently attached to the second contact 404. In figure 4, the connecting member 406 is in the fully closed position. In the fully closed position, the connecting member 406 makes is flush with the first contact 402 maximizing the contact area and minimizing the resistance of the relay. An input 410 is connected to serpentine conductor 402 and an input 412 is connected to the second contact 404.

Figure 5 is a front view of the relay in the open position. The side view shows that the serpentine conductor that forms the first contact 402 has many contact points along its length. The serpentine conductor 402 becomes narrower along its length, which increases the resistance of the serpentine conductor. In the open position, the connecting member 406 is bent away from the serpentine conductor 402 so that there is no contact between the serpentine conductor and the connecting member 406. In the open position current can not flow from the serpentine conductor 402 to the second contact 404 or vice versa.

Figure 6 is a perspective view of the relay with the connecting member 406 removed so that the configuration of the connecting member can more easily be viewed. In figure 5 the zig-zag configuration of the serpentine conductor 402 can be seen. Also the width of the serpentine conductor 402 becomes narrower as it moves away from input 410, increasing the resistance. As the connecting member 406, shown above in this figure, begins to move towards the substrate 408, it first contacts the serpentine conductor at its extreme from input 410. The relay has now closed, but there is a large resistance between inputs 410 and 412 because the current must travel the entire length of the serpentine conductor. As the connecting member moves progressively down towards the substrate 408, it contacts the serpentine conductor closer 402 and closer to the input 410, and the resistance across the switch decreases. Finally the connecting member shorts out the entire serpentine conductor 402 and makes contact at the base of the input 410 giving the minimum resistance for this relay.

Figure 7 is a top view of a dynamic antenna 700 that uses micro relays to change the antenna's size and shape. Figure 7 shows a silicon wafer 704 covered with small gold squares 702. Each one of these gold squares 702 is an antenna element (an antel). The antenna elements 702 can be electrically connected together to form an antenna of the desired shape and size. Micro relay switches will be between the antenna elements interconnecting the elements. By opening and closing the appropriate relays, an antenna of the desired shape and size can be configured. In a typical design the gold squares 702 may be 200 microns on a side, and separated by 50 micron air gaps. On a 4 inch wafer there can be about 12,000 of these gold squares 702. The shape, size, and interconnectability of the gold squares 702 are design parameters the antenna designer can conveniently specify.

In figure 8, certain of these gold squares 702 have been electrically connected together to form a loop antenna. (The elements connected together have are shown in a darker shade of gray.) If one wants a different impedance, different elements are interconnected to form a slightly different sized loop.

Different antenna arrays can be configured as easily as connecting different antenna elements together. Figures 9, 10, 11, and 12 show a few of the many possible antenna designs.

Figures 13, 14, and 15 show a preferred way of controlling the antels 702. Figure 13 shows that there are three groups of control lines going into the intelligent antenna array 700. (In the present example, the intelligent antenna is shown as rows and columns of antels 702 on a round silicon wafer 704.) These control lines are Data 1302, Column Address 1304, and Enable 1306. At each intersection of these three control lines is a set of micro relays 1400, shown in figures 14 and 15 that control whether this antel is connected to the next antel 702. By using control lines 1302, 1304, and 1306, each antel 702 can be electrically connected to the four nearest neighboring antels.

In operation a single column of antels is controlled during each programming cycle. Initially the Column Addresses 1304 and Enable lines 1306 have low voltage, or zero voltage. During the first programming cycle, data is entered on the Data control lines 1302. This data controls which relay sets 1400 are to be closed or open. The Column Address line 1304 for the column to be program is activated, or brought to a high voltage state, and then the Enable line 1306 for this column is brought high. This latches the data into this column, and the desired relay sets in this column are kept on or off as desired during the rest of the program cycles. As long as the Enable line 1306 on this column is kept high, the data will remain latched into this column

and the correct relays 1400 will remain open or closed in this column. Next the data for the next column to be programmed is placed on the Data lines 1302 and the Column Address 1304 and Enable line 1306 for the next column being programmed are brought high, latching this data in the second column to be programmed. This cycle is continued until all the desired columns are programmed and the appropriate relays 1400 connecting the antels 702 are open or closed.

To re-program a column, the Data line 1302, the Column Address line 1304 and the Enable line 1306 for that column are brought low. Then the programming cycle repeats, data is entered on the Data lines, and that Column Address and Enable line are brought high.

A relay that responds to voltage changes in the Data, Column and Enable lines is shown in figure 14. Applying a voltage to the Data line applies a voltage to the electrode on the substrate labeled 1402. This pulls the connecting member 1410 towards the substrate 1412 in the region of the electrode 1402. Next applying a voltage to the Column line applies voltage to the electrode on the substrate labeled 1404. This pulls the connecting member 1410 down over the region over electrode 1404. Finally applying a voltage to the Enable line applies a voltage to the electrode on the substrate labeled 1406. This pulls the connecting member 1410 all the way, so that connecting member 1410 makes contact with variable resistance contact 1408 closing the switch. As long as electrode 1406 is activated, it will hold the connecting member down 1410 to the substrate and keep the switch 1400 closed regardless of what electrodes 1402 and 1404 do.

To re-program the column, electrodes 1402, 1404, and 1406 are brought low, the relay 1400 opens, and the programming cycle starts again. During subsequent programming cycles when other columns are being programmed, the Column line

programmed above is kept low, and this inhibits other programming cycles from closing the switches in this column.

Figure 15 shows several antels 702, and in the blow up, three connecting members 1410 attached to three relays are shown with the Data line 1302, Column Address line 1304, and Enable line 1306 beneath these connecting members 1410. Again, as voltages are applied to control lines 1302, 1304, and 1306 in the correct sequence, the relay is latched closed, connecting the antels 702. However if any of these lines is not activated, the switch will not close during this programming cycle.

Having now fully described this invention, it will be appreciated by those skilled in the art that the invention can be performed within a wide range of parameters within what is claimed, without departing from the spirit and scope of the invention.

What is claimed is:

1. A relay comprising:

a substrate;

a variable resistance contact attached to the substrate, wherein the resistance of the variable resistance contact varies along its length; and

a connecting member configured to contact the variable resistance contact at positions of increasing resistance during opening and decreasing resistance during closing.

2. The relay of claim of 1, wherein the relay is less than 2 millimeter in length.

3. The relay of claim 1, wherein the variable resistance contact comprises a serpentine conductor.

4. The relay of claim 1, wherein the connecting member is flexible.

5. The relay of claim 4, wherein the flexible member is curved away from the substrate when the relay is open.

6. The relay of claim 1, wherein the connecting member is configured to respond to an electrostatic force.

7. The relay of claim 6, wherein the electrostatic force is produced by inter- digitated electrodes attached to at least one surface of the substrate or connecting member.

8. The relay of claim 1, wherein the connecting member is configured to respond to a magnetic force.

9. The relay of claim 1, wherein the connecting member is configured to respond to a piezoelectric force.

10. The relay of claim 1, wherein the connecting member is configured to respond to a thermally generated force.

11. The relay of claim 1, wherein the connecting member is configured to respond to a force produced by bimorph.

12. The relay of claim 1, wherein the connecting member is configured to respond to a force produced by a boiling bubble.

13. The relay of claim 1, further comprising a second contact, wherein a non conducting layer exist between the variable resistance contact and the second contact when the switch is open.

14. The relay of claim 13, wherein the non conducting layer is a sacrificial layer.

15. The relay of claim 1, fabricated using a layer of silicon dioxide between the contact points that is later dissolved in a solution containing hydrofluoric acid.

16. The relay of claim 1, wherein the variable resistance contact is a conductor selected from the group consisting of gold, platinum, chrome, titanium, and mercury.

17. The relay of claim 1, wherein the substrate comprises a silicon surface.

18. The relay of claim 1, wherein the substrate comprises a glass surface.

19. The relay of claim 1 wherein a plurality of relays are placed in parallel and series to produce an array.

20. The array of claim 19, wherein resistors are placed between the relays of the array, wherein the resistance of the array can be controlled by opening and closing relays in the array.

21. A method of preventing arcing between a contact and a connecting member in a relay comprising:

providing a relay comprising at least one variable resistance contact and at least one connecting member, wherein the resistance of the variable resistance contact varies along its length;

contacting the variable resistance contact at positions of increasing resistance during opening of the relay; and

contacting the variable resistance contact at positions of decreasing resistance during closing.

22. The method of claim 21, wherein the variable resistance contact comprises a serpentine conductor.

23. The method of claim of claim 21, wherein the relay is less than 2 millimeters in length.

24. A dynamic antenna comprising;

a plurality of antenna elements; and

relays interconnecting the antenna elements, wherein each of the relays comprise a substrate, a variable resistance contact attached to the substrate, wherein the resistance of the variable resistance contact varies along its length, and a connecting member designed to make electrical contact at several positions along the variable resistance contact.

25. The dynamic antenna of claim 24, wherein the configuration of the dynamic antenna can be changed by connecting together antenna elements by closing individual relays.

26. The dynamic antenna of claim 24, wherein the impedance of the dynamic antenna is changed when the configuration of the dynamic antenna is changed.

27. The dynamic antenna of claim 24, wherein the antenna elements and the relays are fabricated on the same substrate.

28. The dynamic antenna of claim 24, wherein the antenna elements comprise a conducting metal.

29. The dynamic antenna of claim 24, wherein the relay further comprises three electrodes beneath the connecting member, and wherein the three electrodes are connected to three different control lines.

30. The dynamic antenna of claim 29, wherein the three control lines are used to control the opening and closing of the multiple relays of the dynamic antenna in a multiplexed manner.

31. A method of making a dynamic antenna comprising:

providing a plurality of antenna elements on a substrate;

connecting each antenna element to each adjacent element using a relay, wherein the relay comprises a substrate, a contact attached to the substrate, wherein the resistance of the variable resistance contact varies along its length, and a connecting member configured to make electrical contact at several positions along the variable resistance contact.

32. A relay array comprising:

a plurality of relays, wherein each of the relays comprise:

a substrate;

a variable resistance contact attached to the substrate, wherein the resistance of the variable resistance contact varies along its length;

a connecting member configured to contact the variable resistance contact at positions of increasing resistance during opening and decreasing resistance during closing; and

three electrodes placed beneath the connecting member, wherein the three electrodes are connected to three different control lines.

33. The relay array of claim 32, wherein a relay is closed by activating all three electrodes beneath the relay's connecting member.

34. The relay array of claim 32, wherein a closed relay can be maintained in the closed position by a single active electrode.

35. The relay array of claim 32, wherein the three different control lines are connected to a plurality of relay electrodes in the relay array.

36. The relay array of claim 32, wherein the three control lines are used to control the opening and closing of multiple relays of the relay array in a multiplexed manner.

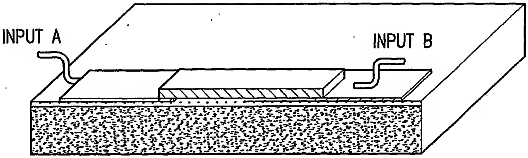

FIG.1

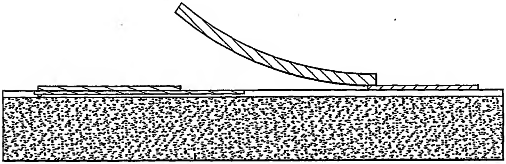

FIG.2

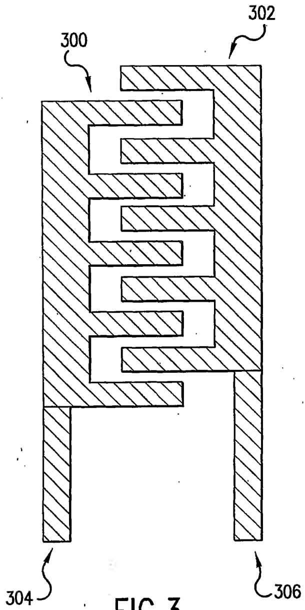

FIG.3

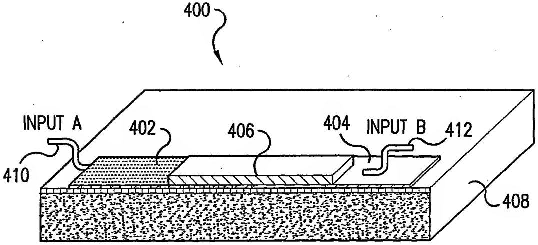
400
INPUT A
402
406
404
INPUT B
412
410
408

FIG.4

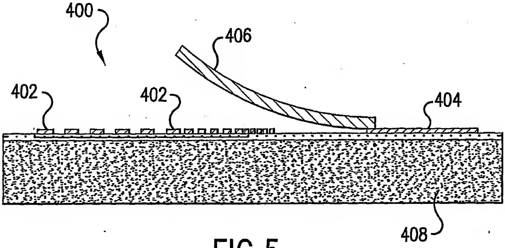
400
406
402
402
404
408

FIG.5

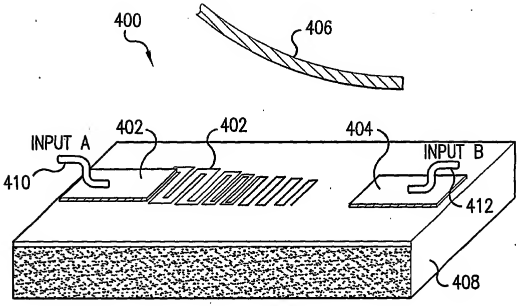

FIG.6

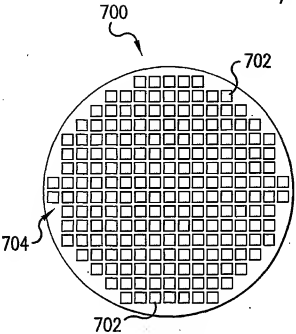

FIG.7

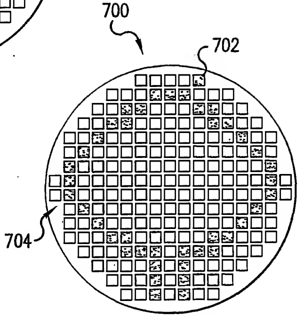

FIG.8

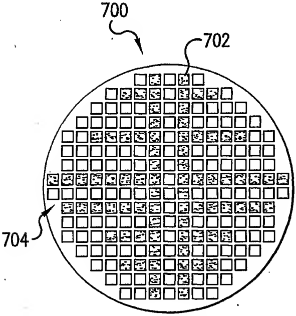

FIG.9

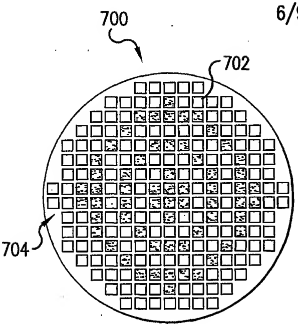

FIG.10

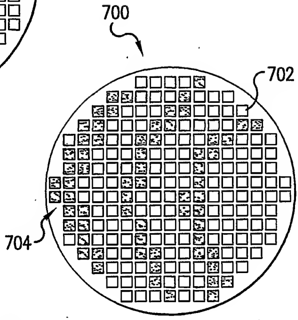

FIG.11

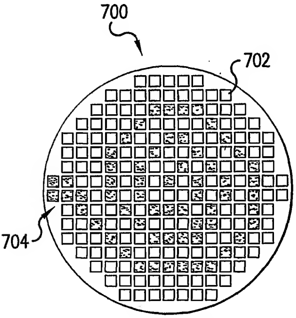

FIG.12

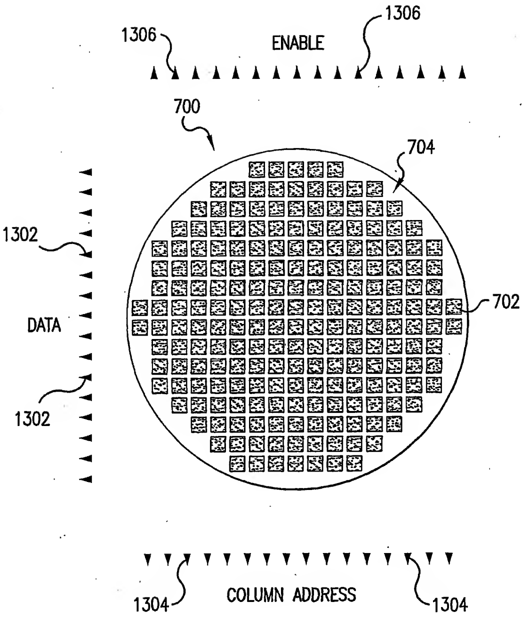
1306
ENABLE
1306
700
704
1302
DATA
702
1302
1304
COLUMN ADDRESS
1304

FIG. 13

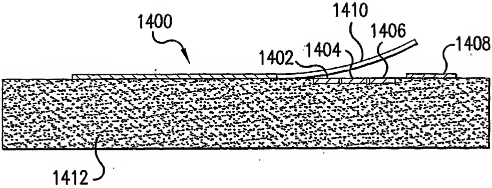

FIG. 14

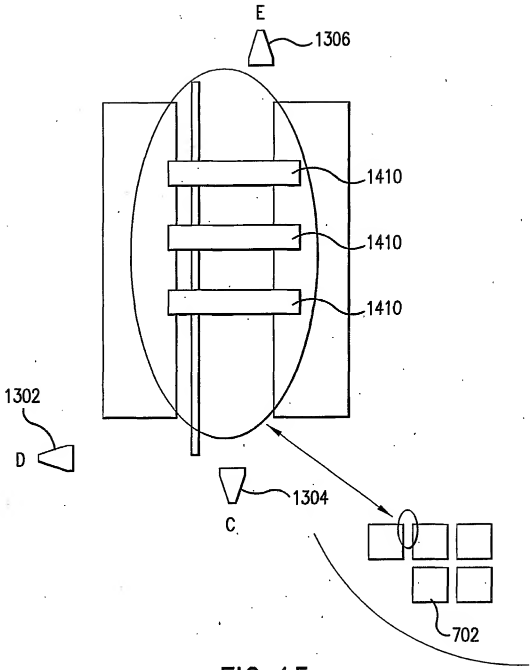

FIG. 15